ASCOT

ATMOSPHERIC STUDIES IN COMPLEX TERRAIN

Manuscript date:
November 1984

UCID–18878–84
ASCOT 84–6

ASCOT FY-1984 PROGRESS REPORT

Paul H. Gudiksen
Marvin H. Dickerson
Tetsuji Yamada

Lawrence Livermore National Laboratory
Livermore, California 94550

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

ASCOT FY-1984 PROGRESS REPORT

Paul H. Gudiksen and Marvin H. Dickerson

Lawrence Livermore National Laboratory, University of California
Livermore, California

Tetsuji Yamada

Los Alamos National Laboratory, University of California
Los Alamos, New Mexico

INTRODUCTION

The ASCOT program, initiated in FY–1978, focused its initial efforts on the study of pollutant transport and diffusion associated with nocturnal drainage flows in a complex mountain valley in The Geysers geothermal area in northern California. Three major multi-laboratory field studies were conducted in this area; while several smaller scale studies were carried out by individual laboratories on simpler two-dimensional slopes at supplemental study sites. Analysis of the resulting data provided the additional insight into the physics of drainage flows needed for the model development activities. The program supports a wide spectrum of modeling concepts that include one-, two-, and three-dimensional hydrodynamic as well as three-dimensional diagnostic models for both research and application needs. Technical progress reports were published during FY–1983 that summarize the significant achievements. A transition of the field studies part of the program to the oil shale region of western Colorado was initiated during FY–1982 to (1) test the transferability of the methodologies developed in The Geysers to a new environmental setting, and (2) extend the studies to include not only the nocturnal valley flows, but also the morning transition and daytime flows. Thus, a series of exploratory field studies, were carried out during July 1982 in the Brush and Roan Creek valleys that are situated about 40 miles northeast of Grand Junction. Results from these studies in conjunction with model calculations, provided a basis for planning a comprehensive series of field experiments that were conducted during September-October 1984.

This report briefly summarizes the major program activities during FY–1984. This includes the conduct of a data analysis workshop, a description of the field experiments, and a summary of the modeling activities. A list of references are also included to allow readers to acquire more details in their respective areas of interest.

DATA ANALYSIS WORKSHOP

A data analysis workshop, attended by approximately 20 ASCOT participants, was held at LLNL, November 7–11, 1983. The purpose of the workshop was to formulate the critical physical concepts and the appropriate modeling framework needed to simulate pollutant transport and diffusion in nocturnal drainage flows. The data used by the participants were acquired during three field experiments in The Geysers area and one exploratory study in western Colorado as well as smaller scale studies performed at the supplemental study sites. A report of the workshop discussions has been published (ASCOT 84–7). The following provides a brief synopsis of the report. The specific areas under consideration were:

- Evaluation of the spatial and temporal variability of drainage flows along slopes and within basins in The Geysers area.
- Evaluation of pooling region phenomena in The Geysers area.
- Evaluation of current theories of drainage flows on simple slopes.
- Evaluation of the characteristics of the flows observed within the Brush Creek valley.

Analysis of the surface wind and temperature data acquired in The Geysers yielded clear differences in regard to the spatial and temporal variability in the flows observed near the ridges, over the upper and middle slopes, within the basin, and within the outflow region. This, at least in part, is due to the influence of the ambient winds at the upper levels on the drainage flows. A common 1–2 hour period of variation, however, appears to persist throughout the study nights. The upper air observations within the Anderson Creek valley in The Geysers area show evidence of recirculation features that are several hundred meters in depth and variable in time. Likewise, inversion depth fluctuations, with periods of about one hour, were also in evidence during some experimental periods. Several mechanisms were proposed to account for these variations. These included internal waves generated on top of and within the pool of cool air residing within the Anderson Creek valley basin by seiche effects, topographically-driven buoyancy waves produced by the numerous local outcroppings, as well as by dynamical instabilities due to strong density gradients. In addition, the merging of flows of different densities formed within the many different flow channels, and their interactions with numerous surface obstacles served to contribute to the observed spatial and temporal variations.

Evidence of convergence-induced pooling of the drainage flows within the Anderson Creek valley was acquired from visual observations of smoke plumes and from analysis of the meteorological observations. This pool of cool air, which typically displayed depths of 200 to 400 meters above the basin floor, exhibited either single or multiple layering with the attendant spatial and temporal variations mentioned above. Erosion from the top by the ambient winds, particularly the northeasterly flows over the ridges, seemed to be effective in altering the characteristics of the pool. As expected, such erosion was noted to markedly affect the surface flows along the slopes and to a lesser extent those within the basin.

Various theories of drainage flows on simple two-dimensional slopes were discussed. A number of different parameters must be considered to account for the characteristics of the observations. Some of these are: geometry of the slope, surface energy budget, direction and speed of ambient winds, interactions of flows with the surface to produce drag and turbulence. One dimensional analytical models are available that account for the gross characteristics of the slope-averaged winds, temperature and depth of the drainage flows on simple slopes. More realistic simulations, however, may be afforded with two-dimensional models which solve the fundamental differential equations governing the drainage flows. Thus, it is possible, for example, to evaluate various turbulence parameterizations as well as forest canopy effects on predicted drainage flow characteristics. Detailed vertical profiles of velocity and temperature may be integrated to give characteristic scales of velocity, thickness, and buoyancy flux which may be used to derive entrainment rates and Richardson numbers. Agreements between various models are generally within a factor of 3 for these quantities for meteorological situations with negligible ambient winds and neutral ambient stratification. Future efforts will concentrate on a more detailed evaluation of the model physics and a comparison of the results with observations.

Observations within the Brush Creek valley in western Colorado revealed typical drainage depths of roughly 150 to 200 meters above the valley floor with speeds of 4 to 8 m/s and centered toward the east side of the valley. The external flows over the ridges seemed to have less of an influence on the characteristics of the drainage flows than in The Geysers. Hence, the spatial and temporal variabilities showed less evidence for the 1 to 2 hour oscillations; however, there appeared to be more evidence for short period dynamic instabilities of 1 to 20 minute frequencies. The downslope flows observed along the steep sidewalls were typically less than two meters in depth with speeds less than 0.2 m/s. Thus, it appears likely that most of the cold air mass supplying the vigorous downvalley flows is fed through the many tributaries along the sides of Brush Creek valley. These observations provided the basis for planning a more comprehensive series of experiments (discussed below) designed to acquire a more detailed examination of the mass, momentum and energy fluxes of the various flows contributing to the Brush Creek drainage flows.

FIELD STUDIES

A series of field experiments was conducted in the Brush Creek valley in western Colorado during a three week period beginning September 17, 1984. These included five experiments designed to evaluate not only the nocturnal flows, but also those during the morning transition and daytime periods. Analyses of previous experiments revealed that a key to enhancing our understanding of pollutant transport and diffusion associated with valley flow regimes was to place more emphasis on evaluating the ambient flows above the valley, the turbulence characteristics of the valley flows, and the surface energy budget. With this in mind, the following specific technical objectives were addressed by these experiments:

- Evaluation of mass, momentum, and energy fluxes of flows along the valley axis.
- Evaluation of mass, momentum, and energy fluxes of slope flows.
  - East and west sidewalls of the valley.
  - Small tributary slopes.

- Evaluation of the transfer of mass, momentum, and energy between the valley and the free airstream above the valley.
- Evaluation of turbulence.
  - Vertical profile of turbulence fluxes along the valley axis.
  - Turbulence fluxes along the sidewalls.
  - Turbulent fluxes at the surface and at valley-free air stream interface.
- Evaluation of the radiative energy exchange at the surface.
- Evaluation of the wind and temperature structure over the region surrounding the Brush Creek valley.

In order to address these objectives, the following experimental plan was developed. For convenience it is divided into the following components:

Valley Axis Flows and Interactions with Meso-scale Flows

To derive the mass, momentum, and energy fluxes along the valley axis, it is necessary to characterize the vertical and horizontal variability of the wind and temperature structure within the valley. Thus, vertical profiles of winds and temperature were measured along several cross-valley arcs, shown in Figure 1, by means of optical anemometer paths across the valley, doppler acoustic sounders, and tethersondes. Additional tethersondes and acoustic sounders were situated within an instrumented tributary (Pack Canyon), and within the confluence of the Brush and Roan Creek valleys. These instruments were operated by a multiplicity of organizations. Organizations providing tethersondes were: ANL, ATDL, CSU, LANL, LLNL, PNL, SNL, SRL, and WPL; while those providing doppler acoustic sounders were: ANL, LANL, PNL, and WPL. The optical anemometers were provided by ANL, ATDL, LLNL, and WPL. These laboratory designations are defined in the back of this report.

A doppler lidar, operated by WPL, was situated at the mid-valley location shown in Figure 1. It provided highly detailed vertical profiles of the wind structure along preselected cross-valley planes to evaluate the change in mass flux as a function of distance along the valley axis. In addition, vertical profiles of the winds above the valley were acquired periodically by scanning in a vertical cone.

Tributary and Sidewall Flows

Since the contribution of the sidewall flows to the valley axis flows is presently poorly understood, the following technical objectives were addressed:

- Evaluate the strength and depth of the nocturnal drainage flows along the sidewalls under varying ambient wind conditions.
- Evaluate the relative importance of tributaries and direct side slope contributions to the valley flows.
- Evaluate the origin of the tributary flows and subsequent merging with the valley axis flows.

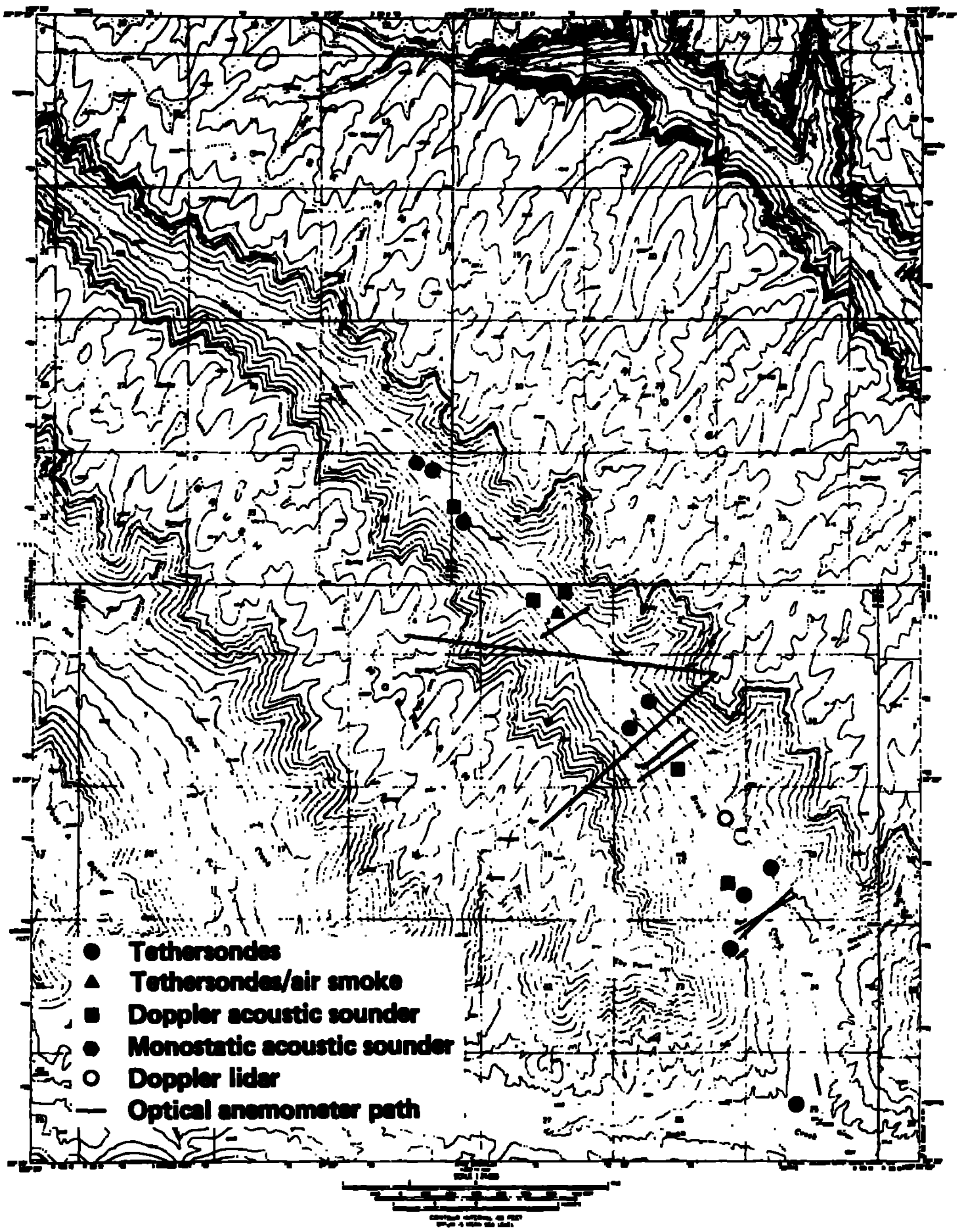

Figure 1. Instrumentation layout for measurement of valley axis flows.

The experimental layout, depicted in Figure 2, shows the optical anemometer paths that provided a measure of the mass fluxes down a specific tributary (Pack Canyon) within the Brush Creek valley. In addition, two optical anemometers were situated along the sidewalls of the Brush Creek valley (only one shown in Figure 2) to define the intensity of the slope flows and their contributions to the main valley flows. Detailed information about the vertical structure of the flows in Pack Canyon was acquired by (1) a high frequency doppler acoustic sounder and a tethersonde operated by ANL and (2) a network of meteorological towers provided by LLNL. The acoustic sounder and the tethersonde were situated at the center of the lower part of Pack Canyon to define the outflow of this tributary into the valley axis flows. The network of towers were situated along the south slope of Pack Canyon as well as along the exposed slope on the eastern sidewall of the Brush Creek valley, as shown in Figure 2, to acquire information on the spatial variability of the slope flows. A monostatic acoustic sounder was also operated by WPL within the next tributary up from Pack Canyon, shown in Figure 2, to evaluate the variability of the contributions of individual tributaries to the main Brush Creek valley nocturnal flows. In addition, towers were also operated by LANL and PNL along the main valley slopes both upstream and downstream from Pack Canyon.

Turbulence and Surface Energy Budget Studies

The objective of the turbulence measurements was to evaluate the variability of u', v', w' and θ' within the valley axis and sidewall flows to permit a determination of heat and momentum fluxes and turbulent kinetic energy, etc. The experimental layout, illustrated in Figure 3, involves the use of a series of tower mounted sonic anemometers and fast response propeller bivanes in conjunction with a vertical profiling system utilizing a balloon supported sonic anemometer. The towers were generally 10–15 m in height with the maximum height of 30 m. These systems were operated by ANL, ATDL, LANL, LLNL, PNL and WPL. The vertical profiling system, operated by a team of scientists from the Japan Environmental Agency, (JEA) acquired turbulence data at selected heights above the valley floor to a height of 500 m. This system was located at the mid-valley location shown in Figure 3.

The PNL performed an exploratory experiment designed to measure the surface energy budgets within the Brush Creek valley. The technique explored the possibility that "Bowen Ratio" energy budget stations, located at the five sites shown in Figure 3, can provide the "ground truth" information that is needed in conjunction with the PNL digitized terrain model and surface temperatures and vegetation cover to derive the surface energy budget of the whole valley. Evaluation of this approach involves comparisons with the thermal energy budget derived from temperature and wind measurements made during the same period within Brush Creek.

Tracer Studies

The objective of the perfluorocarbon tracer releases was to study the behavior of inert pollutants entrained in nocturnal valley flows and the subsequent ventilation of the pollutants into the meso-scale flows during the morning transition period. Specifically, the tracer studies were designed to evaluate:

- Transport and diffusion within the nocturnal valley flows and the transition layer above the nocturnal jet.
- The extent of mixing between the transition layer and the underlying valley flows.
- The merging of tributary slope flows with the nocturnal valley flows.
- The spillover of tracers into adjacent valleys during nocturnal and morning transition periods.

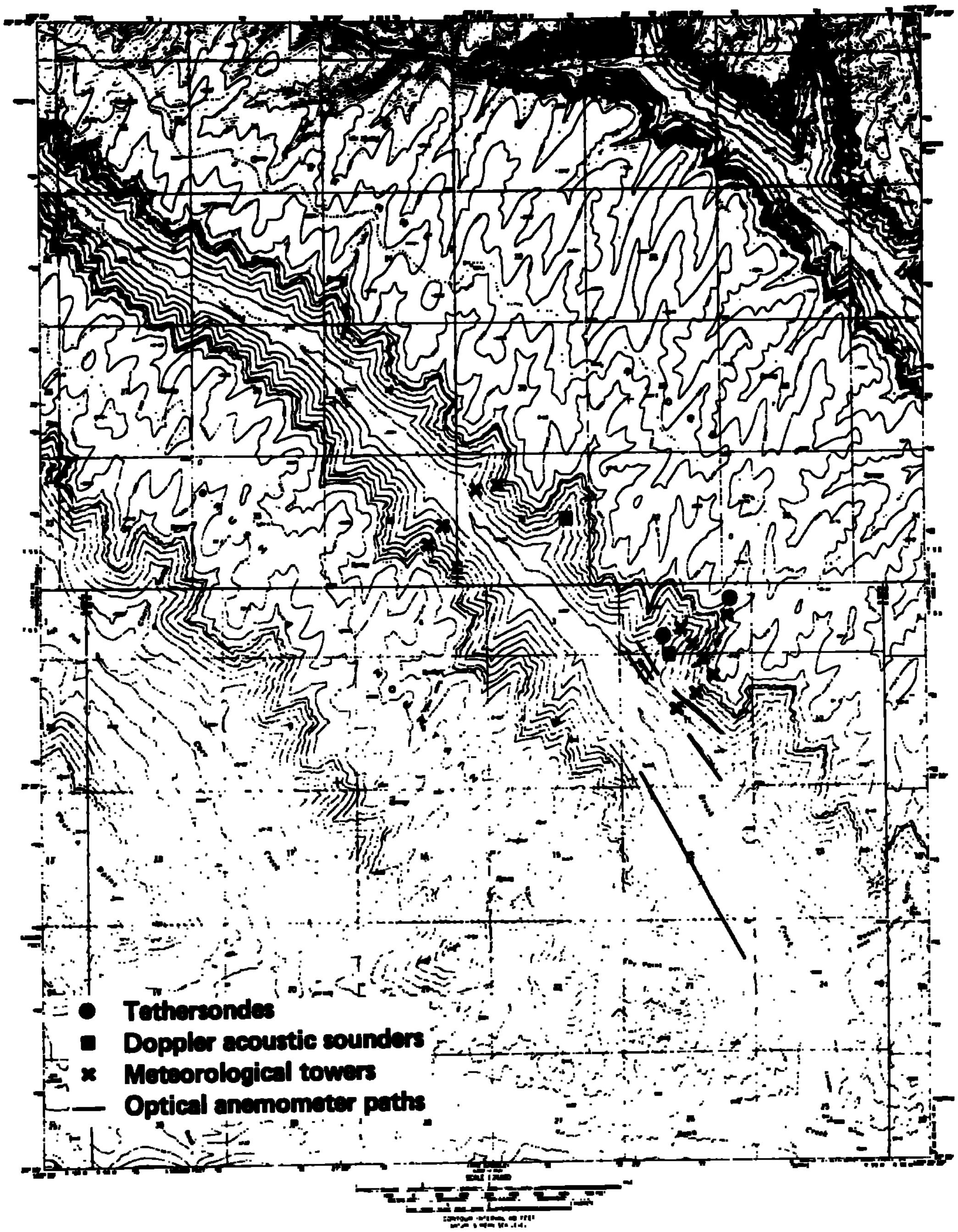

Figure 2. Layout of instrumentation for measuring tributary and sidewall flows.

- The rate of ventilation of the tracers out of the valley during the morning transition period.

The tracer studies were conducted by participants from ARL, BNL, EML, SNL, PNL and the EPA. The experimental design involved simultaneous releases of three perfluorocarbon tracers; two within the Brush Creek valley and one on the mesa. The sampling program utilized extensive networks of surface samplers situated within the Brush Creek

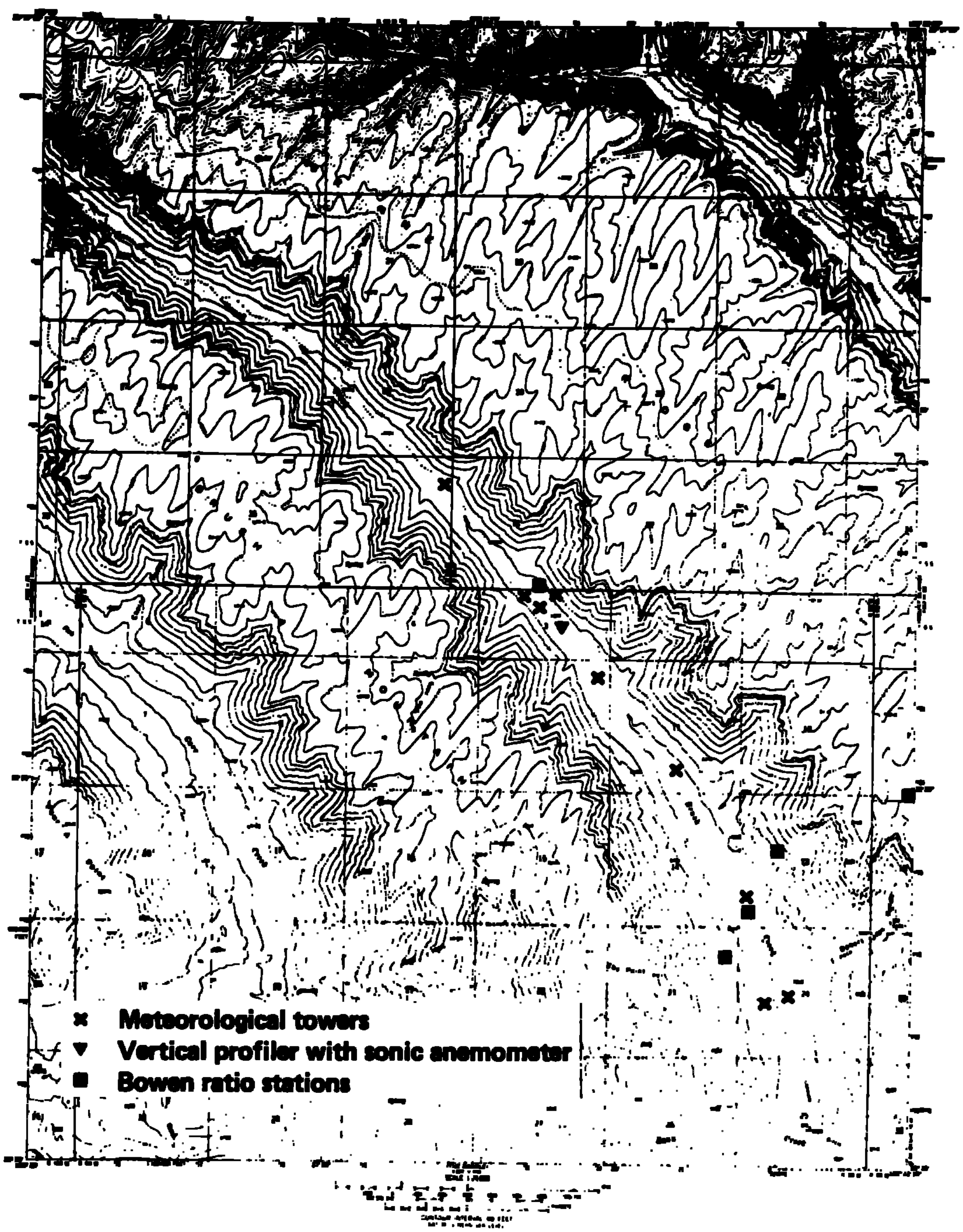

Figure 3. Layout of turbulence instrumentation and Bowen ratio stations.

valley as well as in adjacent valleys and on major ridgetops. In addition, several vertical profiling systems supported the surface sampling networks.

The tracer releases occurred simultaneously and continuously from approximately 0100 to 0900 (local time) to include the morning transition periods. Two of the tracers were released at the surface and at 220 m above the valley floor at the site shown in Figure

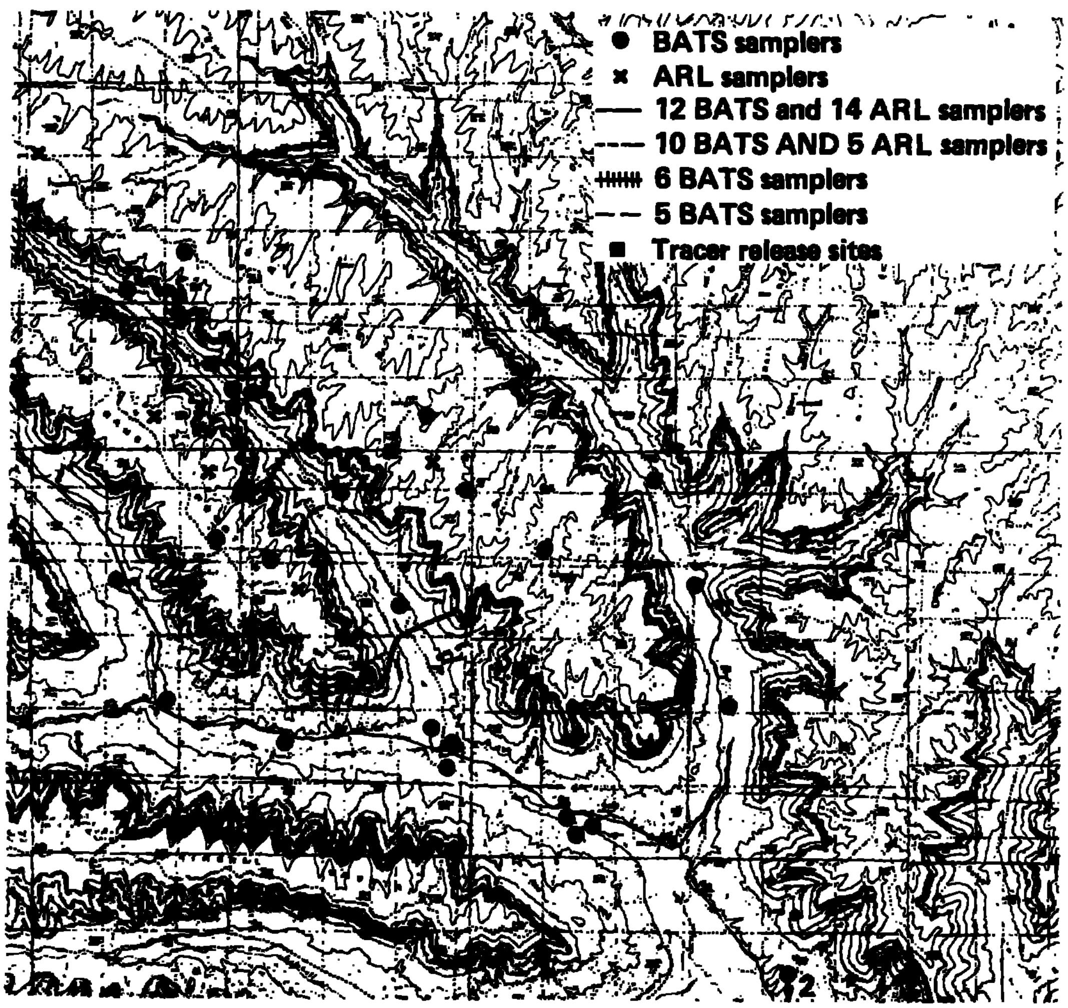

Figure 4. Spatial distribution of perfluorocarbon surface sampling network.

4; while the third tracer was released at the surface from an open area on the mesa just above Pack Canyon.

The surface sampling network consisted of about 60 BATS samplers and 30 additional ARL sampling units to provide the required spatial resolution. The distribution of these samplers is shown in Figure 4. Notice that the majority of the samplers were situated within the Brush Creek valley and the adjacent ridgetops; however, a significant fraction was also devoted to measuring the tracer distributions within adjacent valleys and the Roan Creek valley out to Debeque. The sample collection times varied from 15 to 60 min. In addition, a series of vertical profilers measured the vertical distribution of the tracers as a function of time within Brush Creek valley as depicted in Figure 5. Five vertical profilers utilized the SNL developed sampler; while EML and BNL operated another five profiling systems.

Oil fog was generated by ARL on the mesa top overlooking Pack Canyon for the purpose of visually evaluating the pollutant transport and diffusion properties associated with nocturnal entrainment of air from the mesa top into a tributary and the subsequent

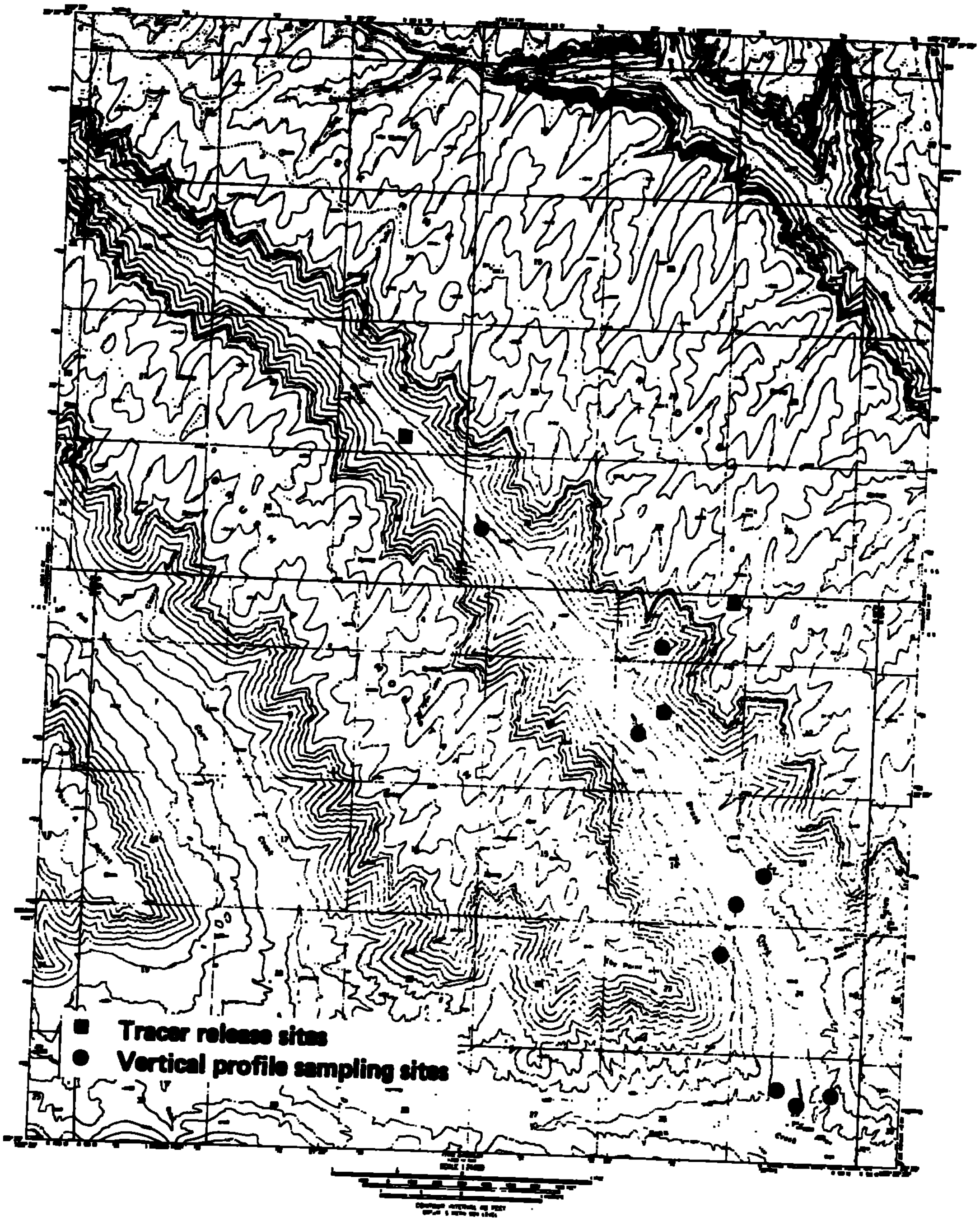

Figure 5. Layout of perfluorocarbon vertical profile sampling sites.

merging of the tributary flows with the main valley axis flows. The oil fog was released over 15 minute periods with sufficient time between releases for the fog to be transported down into and out of Pack Canyon. Photographic documentation of the fog was performed by PNL.

Regional Scale Studies

An exploratory regional scale experiment acquired vertical profiles of winds and temperatures over a 100 km by 100 km region within which the Brush Creek valley is embedded. This data will be helpful in the analysis of the Brush Creek valley data, supplying boundary conditions to numerical models and planning future ASCOT experiments. The experiments included supplemental soundings by the NWS in Grand Junction and three rawinsondes operated by the PNL at Rangely, Meeker, and Rifle. This network provided soundings every three hours over a 24 h period beginning in the afternoon preceding each valley experiment.

MODELING STUDIES

The ASCOT modeling efforts have been focused on the development of analytical, numerical, and statistical techniques in one, two, and three spatial dimensions. These models, which are applicable to a wide variety of situations, have been used to simulate the evolution of nocturnal drainage flows. The one-dimensional models were mainly used for sensitivity studies designed to evaluate the effects of varying parameters such as cloud cover and height, mixing ratios, and forest canopy on the development and intensity of the drainage flows; while the two-dimensional models were used to simulate the characteristics of drainage flows over a simple slope. The following summarizes the most recent simulations by two- and three-dimensional models of the meteorological and tracer data acquired during the 1980 series of field experiments in the Anderson Creek valley situated within The Geysers geothermal area. These results were presented at the DOE/AMS Model Evaluation Workshop held in South Carolina from October 23–26, 1984.

The Anderson Creek valley has the characteristics of a basin. The valley is bounded by Cobb Mountain on the north, by a ridge on the west and south, and by Boggs Mountain on the east. The Anderson, Gunning, and Putah Creeks, which form the principal drainage areas, merge near Anderson Springs with outflow toward the southeast. The elevation differences between the high and low points is approximately 1000 m, and the slopes along the creeks vary from 20° to almost flat in the convergence region. The vegetation varies from dense pine forests to almost bare soil. The September 1980 field studies consisted of five experiments. Each experiment consisted of a series of tracer studies that were coordinated with a host of meteorological observations. Of particular interest to the modeling studies was the release of two perfluorocarbon tracers within the Anderson Creek valley. One of the tracers (PMCH) was released into the nocturnal drainage flows from an open, but very sheltered area in Anderson Creek; while the other perfluorocarbon tracer (PDCH) was released within a forest canopy in Gunning Creek. These sites are roughly halfway up the slopes. The releases were of one hour duration. The surface concentrations were sampled throughout the valley at roughly 50 locations, and two vertical profiling systems were used to define the vertical distributions of the tracers.

The model development activities at SRL have been focused on a two-dimensional dynamical drainge flow model coupled with a Monte Carlo pollutant transport and diffusion model. The equations of motion and mass continuity, reduced to a two-dimensional system by integrating over the drainage layer, are solved numerically in a terrain following coordinate system to define the average wind field of the drainage layer as well as its depth.

Parameterizations for surface drag and interfacial entrainment are included, and the buoyancy force is calculated by assuming that the potential temperature deficit of the drainage layer is constant. The Monte Carlo model simulates the pollutant transport and diffusion processes by advecting clusters of particles by the mean drainage winds and superimposing randomly distributed motions on the particles to simulate diffusion. A simulation of the mean drainage winds observed during Experiment 4, conducted on September 19–20, 1980 in the Anderson Creek valley, is shown in Figure 6. The general flow pattern, the maximum wind speed of about 3 m/s, and a maximum flow depth over the valley basin of approximately 300 m agreed well with the observations. Using this drainage depth averaged wind field, the Monte Carlo model predicted the PDCH perfluorocarbon tracer distribution. Figure 7 shows the predicted distribution during the first two hours after the initiation of the one hour release and a comparison with the observed distribution. These predictions were made on the basis of no ambient winds. Sensitivity studies indicated that inclusion of the observed 2 m/s ambient flows produced only minor influences in the depth averaged wind field and the resultant tracer distribution. Statistical analyses of the results indicate the agreement between predictions and observations at individual sampler sites to be within a factor of five for approximately 40% of the comparisons.

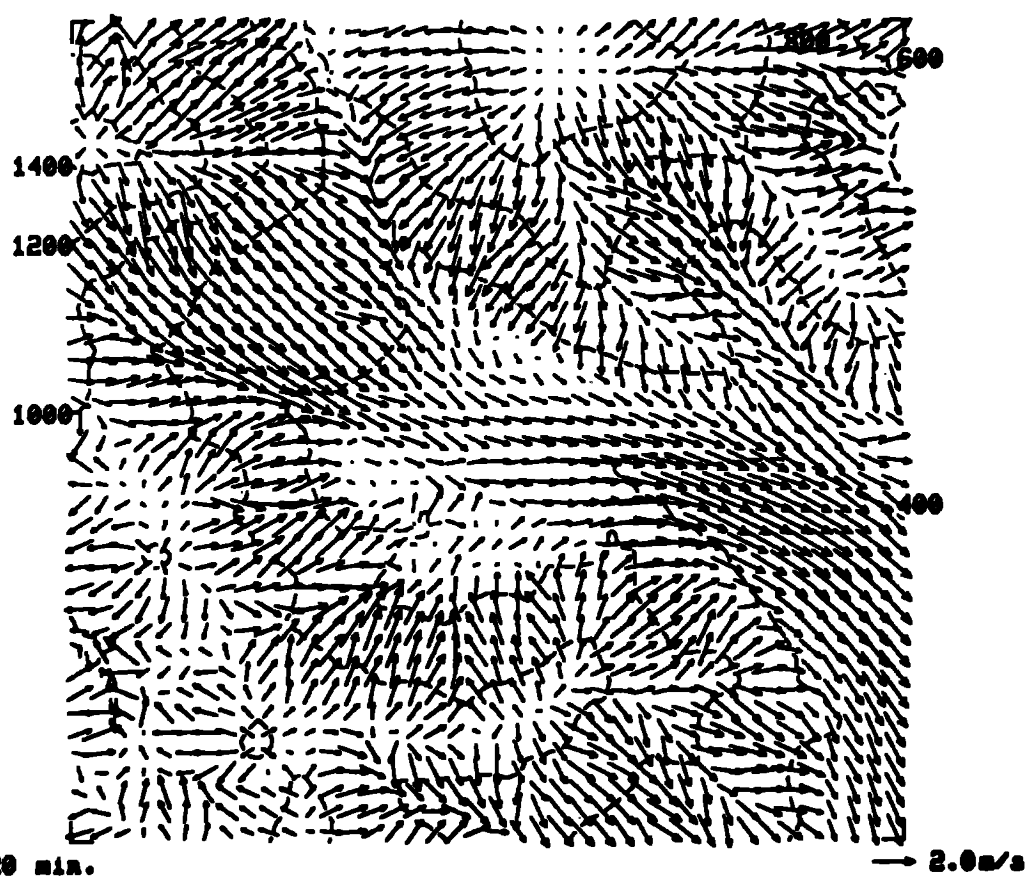

Figure 6. Simulation of drainage flow field for The Geysers area two hours after starting from an atmosphere at rest by means of the SRL two-dimensional dynamical model.

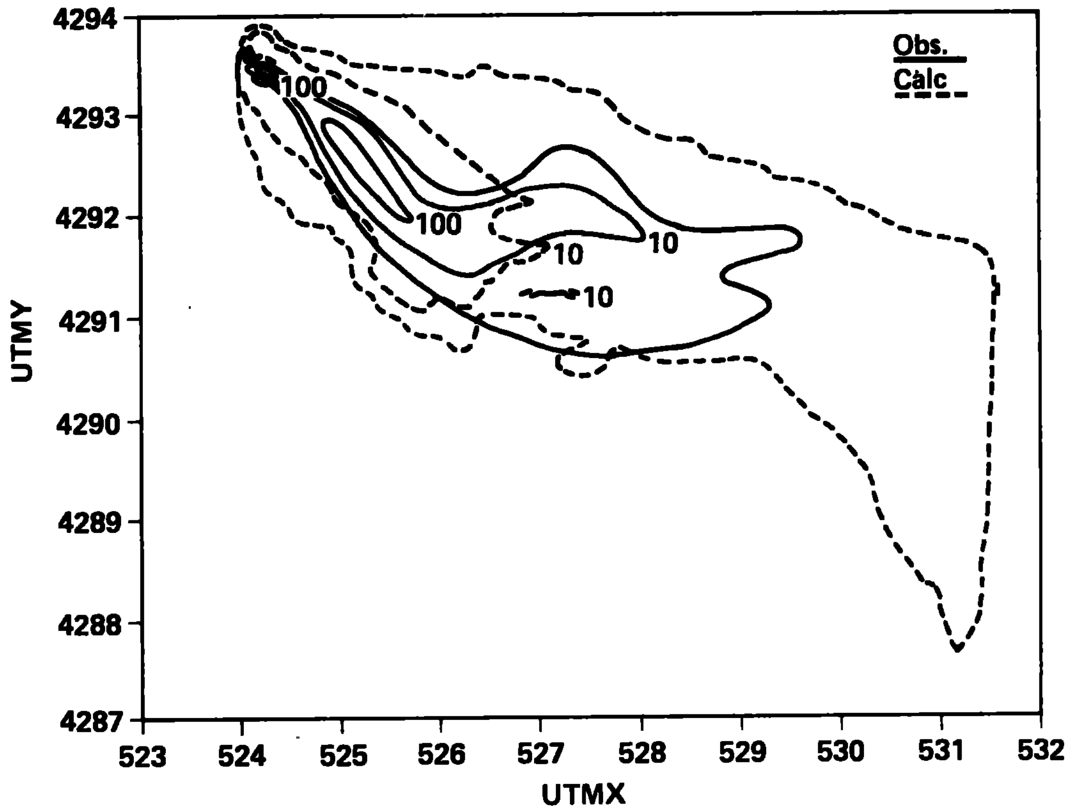

Figure 7. Contours of model calculated PDCH concentrations in ppt integrated over the first two hours after initiation of the release compared with the observations.

To realistically simulate pollutant dispersion over complex terrain, a three-dimensional modeling approach is needed. Therefore, the LLNL developed three-dimensional mass-consistent wind field model (MATHEW) coupled with the three-dimensional particle-in-cell transport and diffusion model (ADPIC) were used to predict the PMCH and PDCH perfluorocarbon concentration distributions within the Anderson Creek valley. The MATHEW model generates mass-consistent three-dimensional gridded wind fields using surface wind observations, vertical wind profiles, and digitized terrain information. Using these wind fields, the ADPIC model calculated the time-dependent distribution of the perfluorocarbon tracers within the valley by the injection of thousands of marker particles into the grid which were transported and diffused within the grid. Simulations of four experiments involving the release of both PMCH and PDCH tracers were performed. To illustrate this modeling approach, it is useful to refer to Figures 8 to 13 which depict the significant features relevent to the experiment conducted on September 19–20, 1980. Figure 8 shows the surface wind observations for a particular hour overlaid over a map of the Anderson Creek valley. On the basis of these observations along with eight vertical profiles of wind speed and direction, the MATHEW model derived the mass-adjusted flow field depicted in Figure 9 for a height of 50 m. Figure 10 illustrates the ADPIC derived PDCH plume at 1 hour and 40 minutes after the end of the one hour release. By summation of the marker particles, the ADPIC model derived the PDCH surface concentration distribution shown in Figure 11, which may be compared with that observed in Figure 12. One notes that the overall computed pattern and levels compare reasonably well with observations; however, topographical and sampling cell resolution problems keep the models from duplicating the narrow creek flow of the tracer in the first kilometer. The model cell size in this calculation was 250 m by 250 m by 50 m. A statistical analysis of over eight hundred comparisons between computed and observed concentrations from the four experiments revealed the results given in Figure 13. Thus, roughly 50% of the comparisons agree within a factor of five. It is of interest to note that this is significantly different from the 50% within a factor of two results acquired from earlier tracer studies performed over the relatively flat terrain areas at INEL and SRL. This degradation in complex terrain may be attributed to the more complex physics encountered and to the enhanced difficulty in collecting representative data.

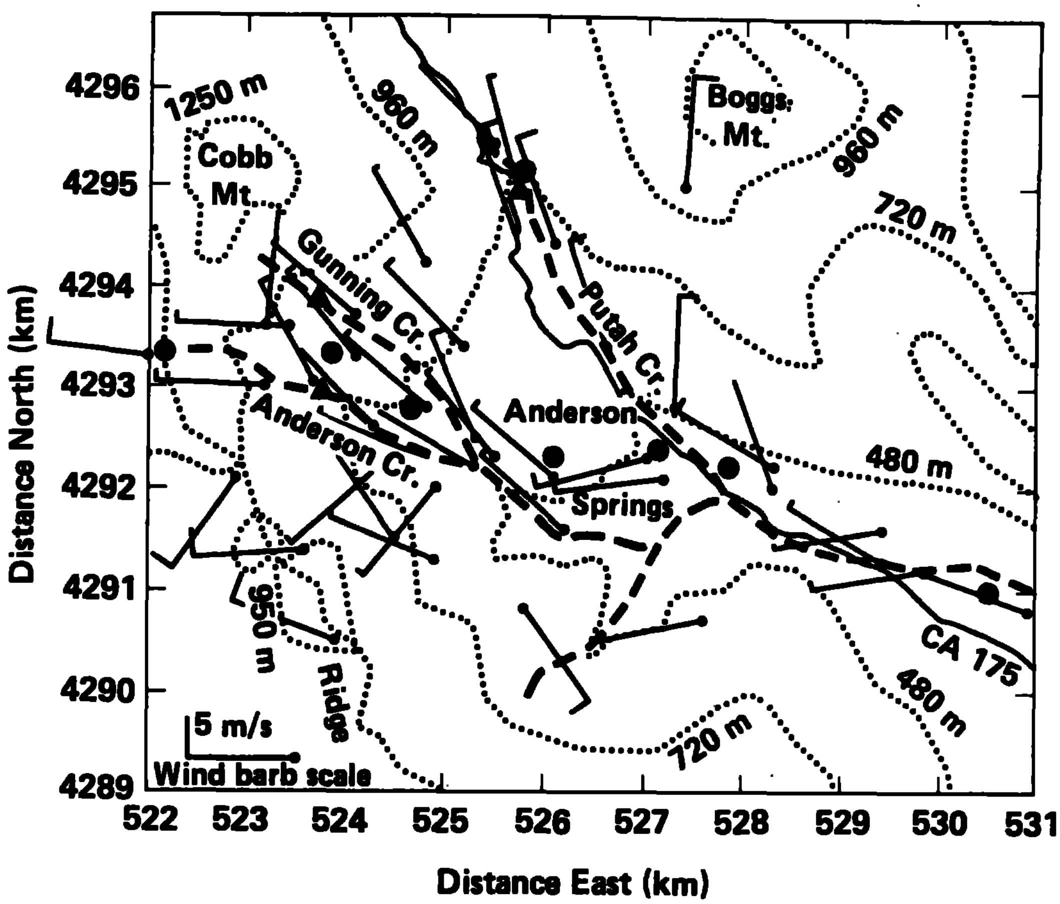

Figure 8. Geography and measurement locations in the Anderson Creek valley. Dashed lines are the Anderson, Gunning and Putah Creeks. Dotted lines are the elevation contours. Solid line is highway CA175. Wind barbs are location of surface stations. Closed circles are locations of vertical profiles. Triangles are tracer release locations.

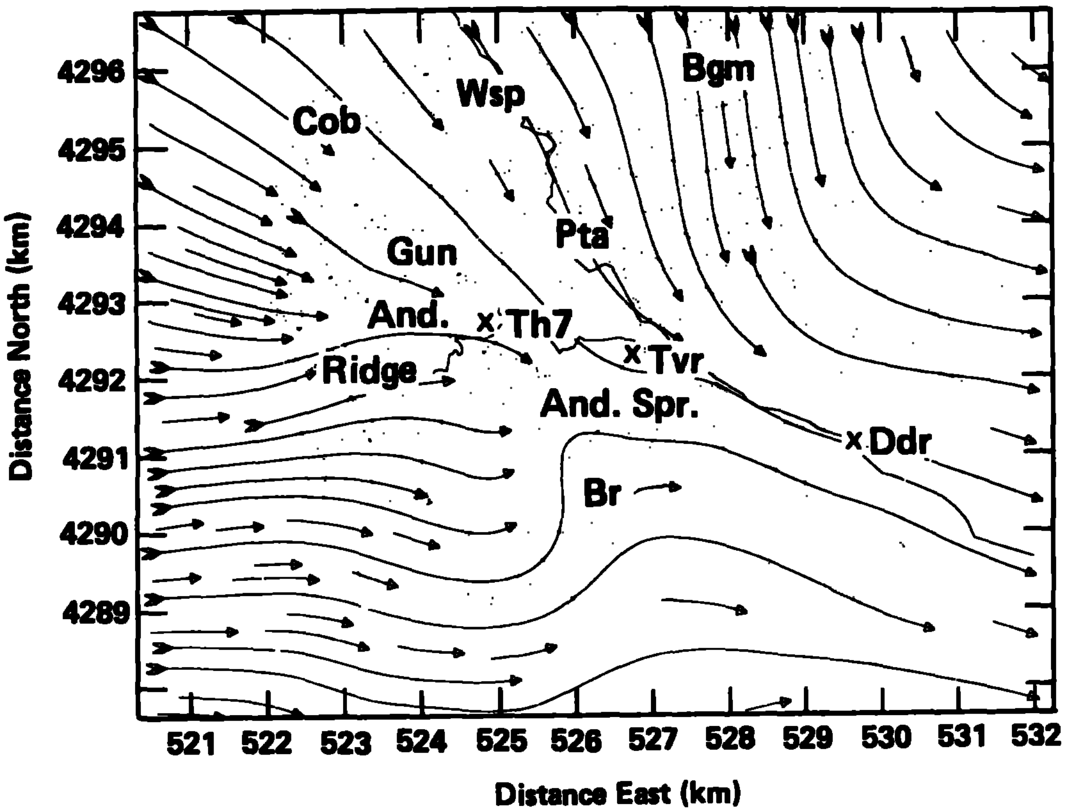

Figure 9. Flow lines of mass-adjusted hourly averaged wind field from MATHEW at 50 m above terrain.

The Los Alamos developed ATMOS1 and ATMOS2 models were also tested for their capabilities to simulate the four perfluorocarbon experiments. ATMOS1 is a diagnostic three-dimensional wind field model with Cartesian horizontal coordinates and a terrain following coordinate in the vertical direction. It utilizes surface and upper air wind observations to derive an interpolated gridded wind field that is iterated on until a mass consistent wind field is created. It has the unique capability to accept wind data from "pseudo" stations calculated by SIGMET, a one-dimensional wind profile model, for areas that are data sparse. This ATMOS1 derived wind field is utilized by ATMOS2, the companion transport and diffusion model, which also incorporates a three-dimensional terrain following coordinate system. The grid used in these simulations consisted of 65 x 34 horizontal cells, each 150 m x 150 m, and 10 vertical cells varying in cell height from 3 m at ground level to 200–300 m at the top of the computational domain. To illustrate the capabilities of these models, Figures 14–16 depict the computed wind fields and PMCH tracer distributions for the experiment conducted on September 15–16, 1980. Analysis of the results for this experiment indicate the agreement between predictions and observations at individual sampler sites to be within a factor of two for 22% of the comparisons; a factor of five for 48% of the comparisons; and, a factor of ten for 65% of the comparisons.

The ASCOT data were also used to evaluate the performance of the LANL developed three-dimensional hydrodynamic model and a random-particle statistical diffusion model.

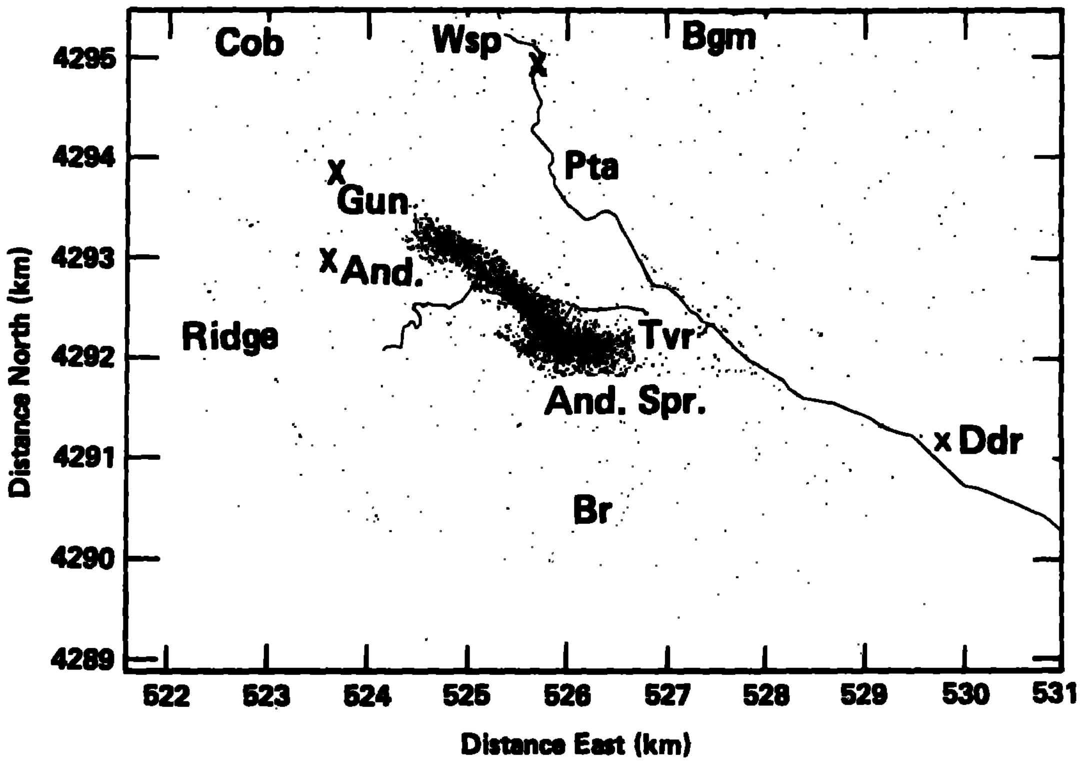

Figure 10. ADPIC model plume of Gunning Creek tracer release at 0140 PST, 1 hr and 40 min after the end of the one hour release.

The hydrodynamic model is composed of the equations of motion, mass continuity, potential temperature, and water vapor mixing ratio; while, turbulence variables are obtained from a set of simplified second-moment turbulence closure equations. The effects of a forest canopy are also included in the model. The initial conditions used to simulate the wind fields for the September 15–16, 1980 experiment were assumed to be easterly through the entire domain at 2200 PST. The radiational cooling occurring on the sloped surfaces causes the air temperature near the surface to decrease throughout the nighttime and to be lower than the air temperature at the same level away from the surface. This temperature difference results in horizontal pressure gradients which produce the downslope flows that are referred to as drainage flows. By 2330 PST the hydrodynamic model has simulated by means of this radiational cooling process the development of organized nocturnal drainage flows close to the surface. This is depicted by the wind vectors shown in Figure 17. As the cooling of the sloped surface continues throughout the night and the air aloft cools by transferring heat energy to the surface, the drainage flows increase in depth even though the geostrophic wind at the top of the computational domain remains easterly at 3 m/s. The drainage layer also increases in depth by the entrainment of air aloft as it moves down the slope. The computed wind profiles at the ridge (RID) indicated easterly flows except within a shallow layer of about 50 m in depth where the wind directions were northeasterly to northerly; while at the TVR site, situated within the valley basin, the drainage layer depth increased to about 200 m. The computed vertical profiles of the horizontal winds

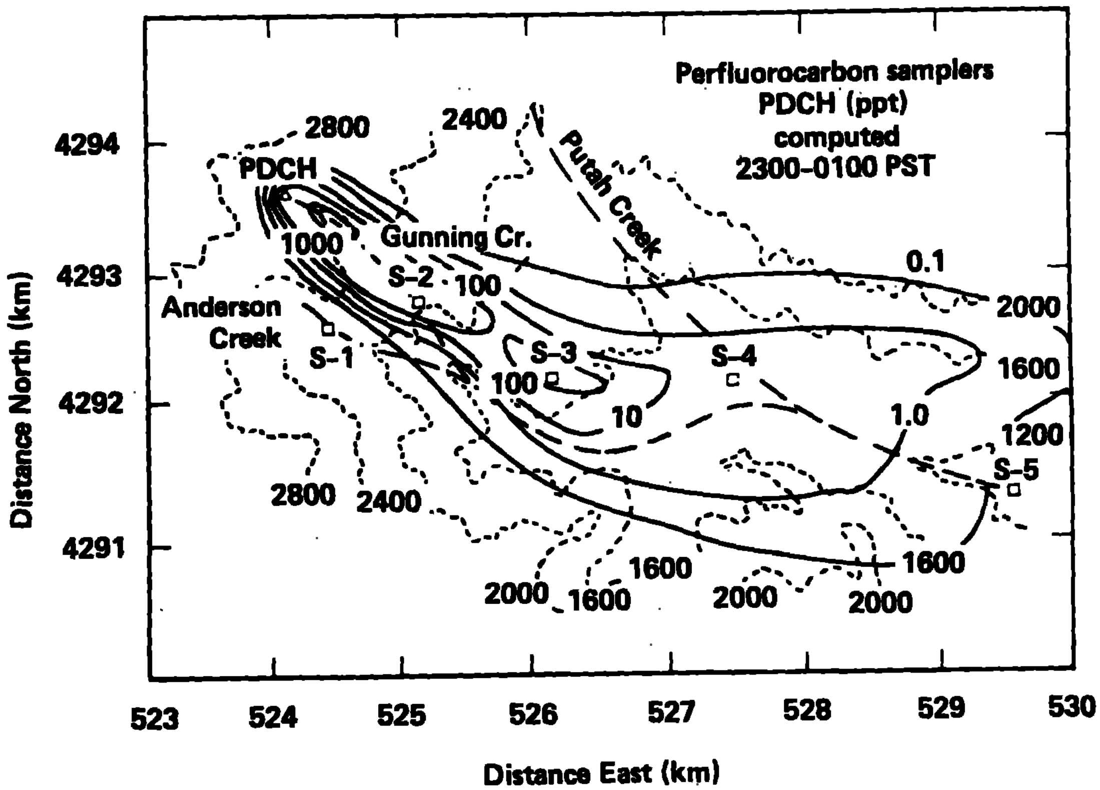

Figure 11. Computed average surface concentrations from Gunning Creek perfluorocarbon (PDCH) release in parts per trillion. Averaging time 2300–0100 PST.

and the values of the standard deviation of the vertical wind speeds σ_w agree qualitatively with the observations.

The observed surface concentration distributions of the perfluorocarbon tracers were used to examine the performance of the random-particle statistical diffusion model. This model utilizes the velocity and velocity variance provided by the hydrodynamic model discussed above. Simulations of the September 15–16, 1980 PMCH tracer distributions are shown in Figures 18–20 at one hour intervals. Particles diffused above the drainage wind layer are transported westward by the ambient easterly flows as shown in Figure 18. The plume is bent slightly toward the north as illustrated in Figure 19 due to the drainage flows that developed over the southern slopes. Its relatively narrow structure within the valley is due to the convergence of drainage flows from the north and south slopes. After the convergent zone, the plume spread rapidly in the horizontal directions as depicted in Figure 20.

By placing an imaginary box of 10 m x 10 m x 4 m (vertical) at each sampling location and counting the number of particles in each box, it is possible to compute the PMCH tracer concentrations. Statistical evaluation of the model performance revealed agreement between predictions and observations to be within a factor of two for 21% of the comparisons; a factor of five for 49% of the comparisons; and a factor of ten for 62% of the comparisons.

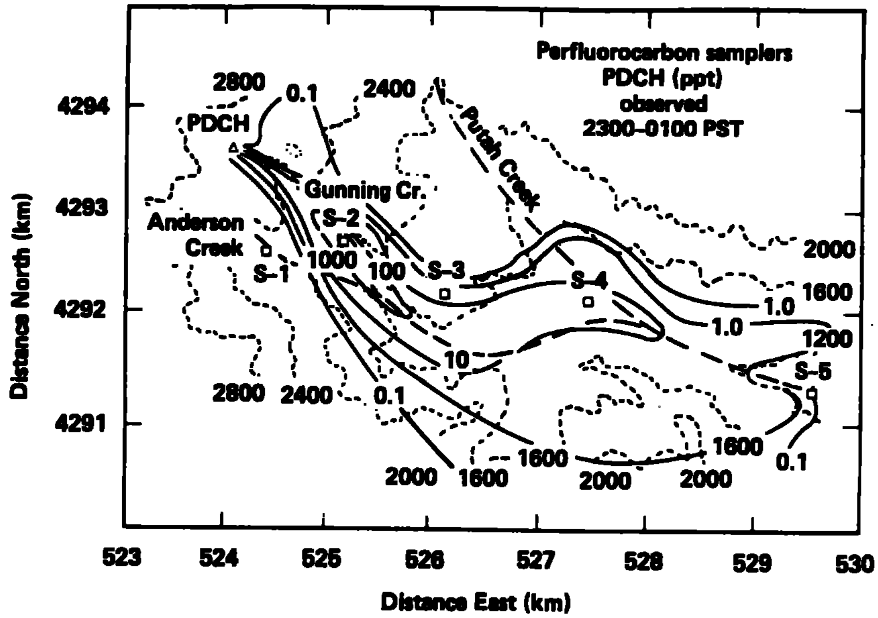

Figure 12. Observed average surface concentrations from Gunning Creek perfluorocarbon (PDCH) release in parts per trillion. Averaging time 2300–0100 PST.

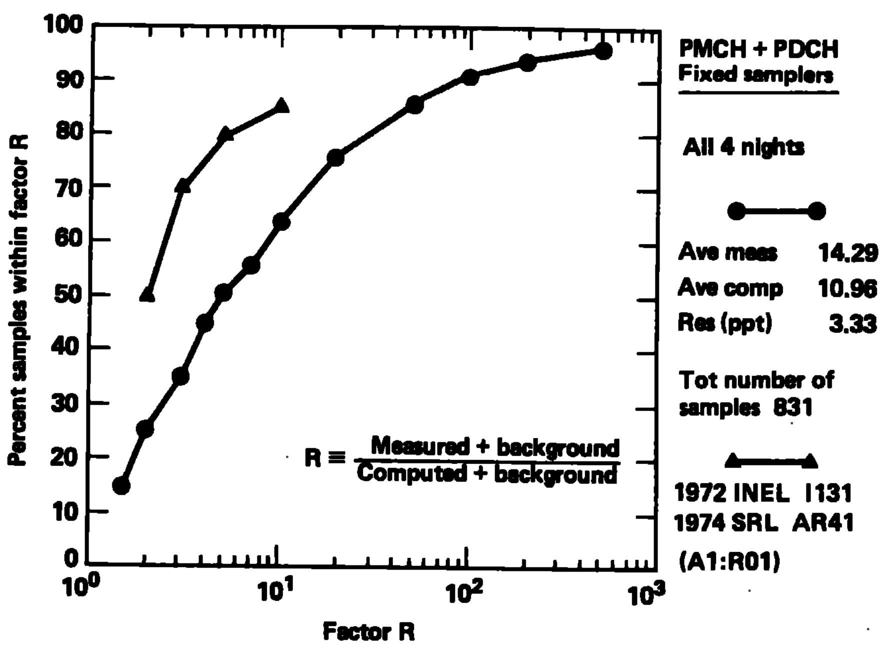

Figure 13. Percentage of computed concentration samples that agree within a factor R with those measured for the PMCH and PDCH tracers for four experiments. These may be compared with values acquired in simpler terrain settings at INEL and SRL.

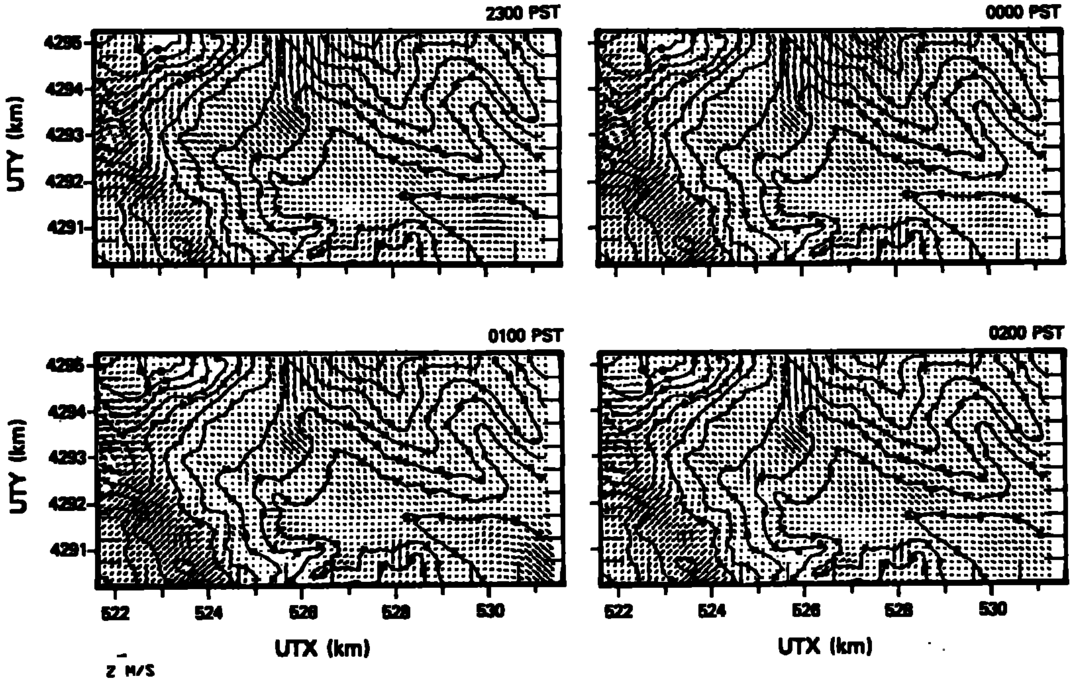

Figure 14. Computed wind fields by ATMOS1 for September 15–16,1980 (Night 2) at 7 m above the ground for hours 2300 0200 PST.

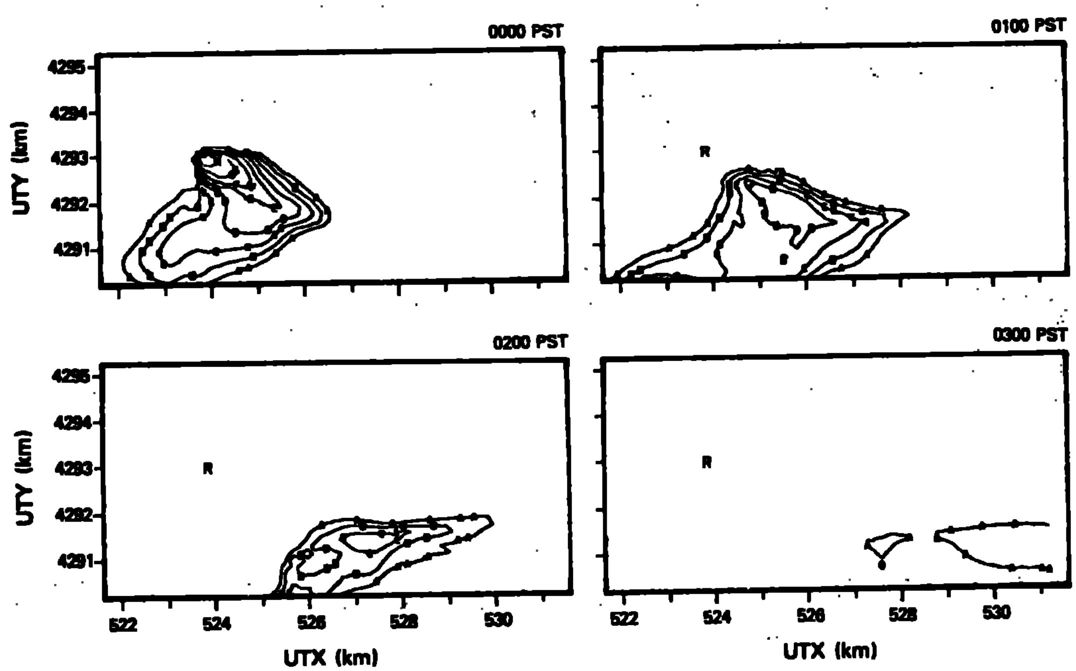

Figure 15. Computed contour lines of PMCH concentrations for Night 2 at 2 m above the ground at 0000, 0100, 0200, and 0300 PST. The lowest contour is 1.0 ppt with an increment of 0.5 ppt.

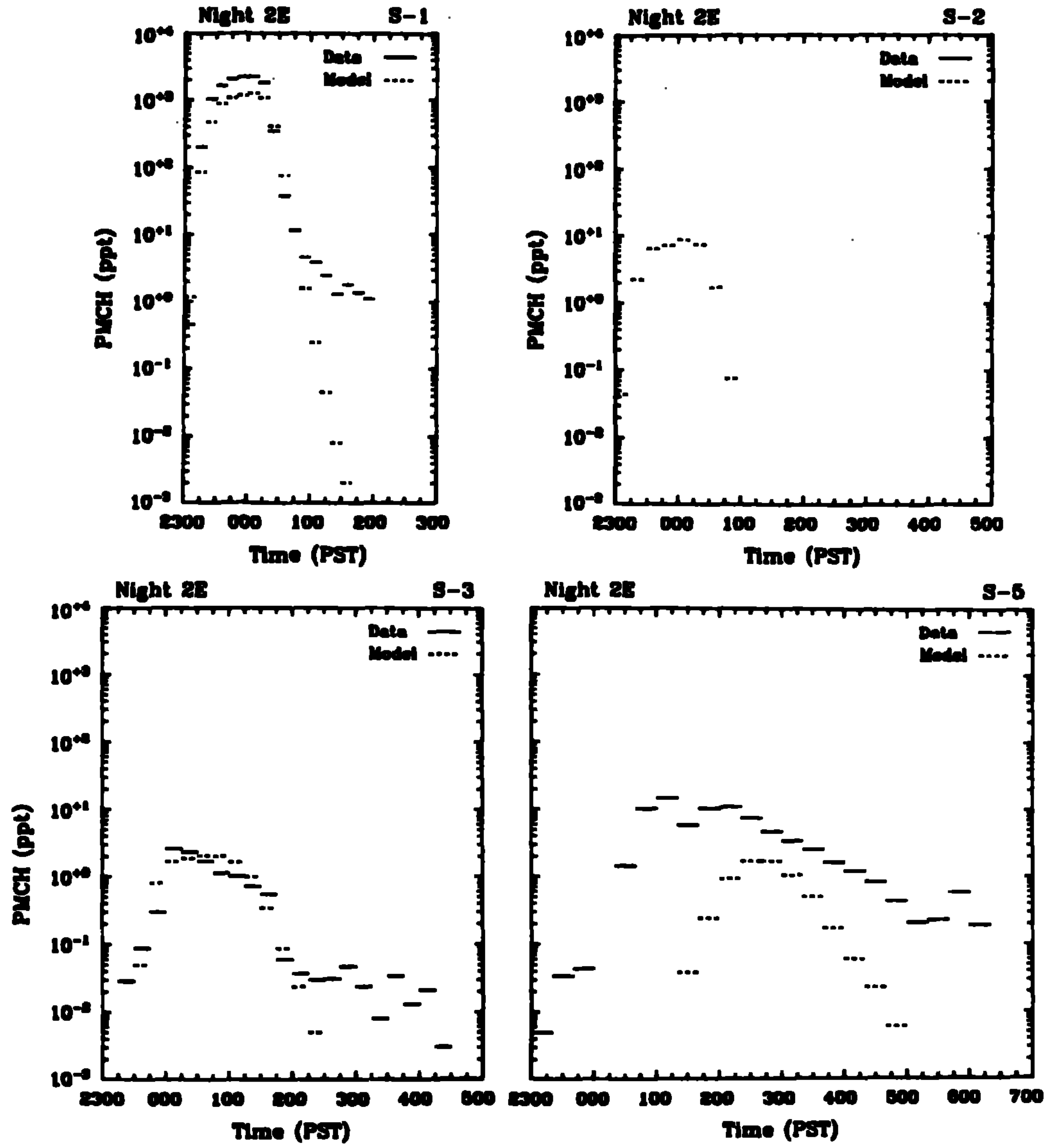

Figure 16. Computed and observed time changes of PMCH concentration for the sequential samplers for Night 2.

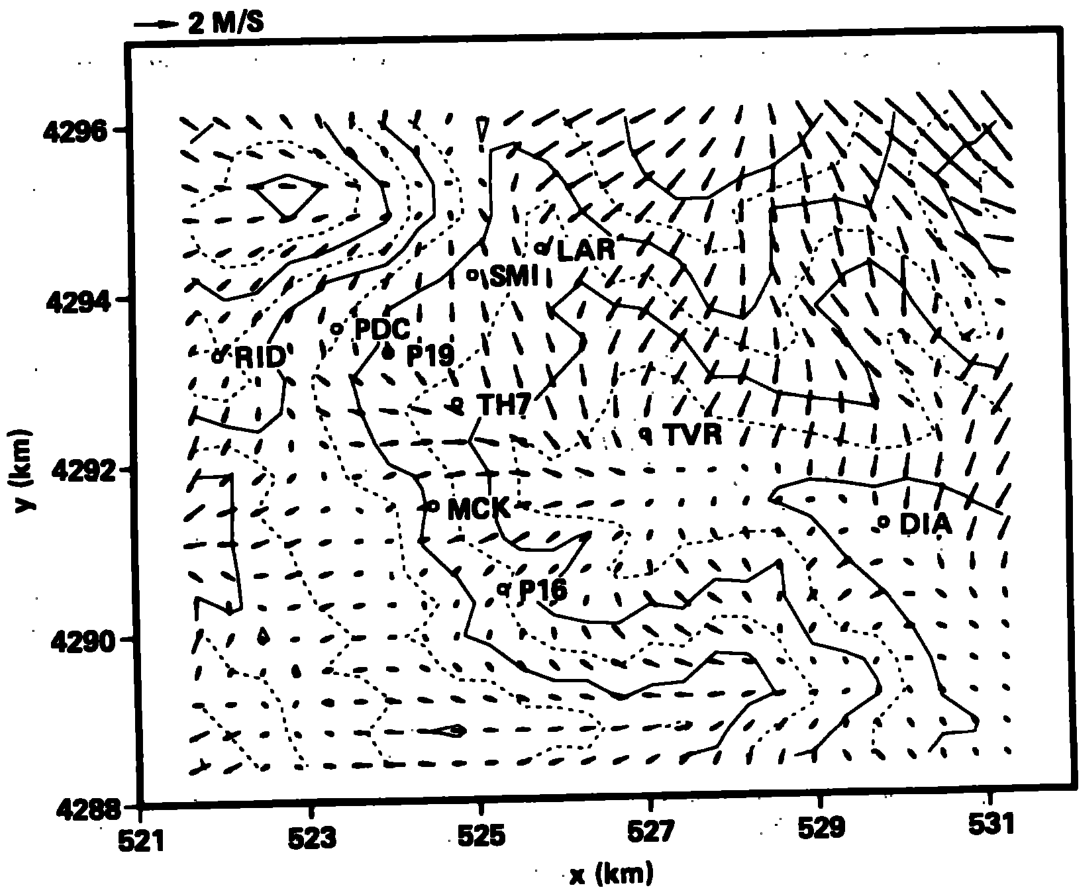

Figure 17. Computed wind vectors for Night 2 at 22 m above the terrain at 2330 PST. Symbols in the figure indicate observational sites. Terrain is contoured by the solid lines with an increment of 200 m. The lowest contour is 400 m above the mean sea level. Dashed lines indicate contours halfway between the solid line contours.

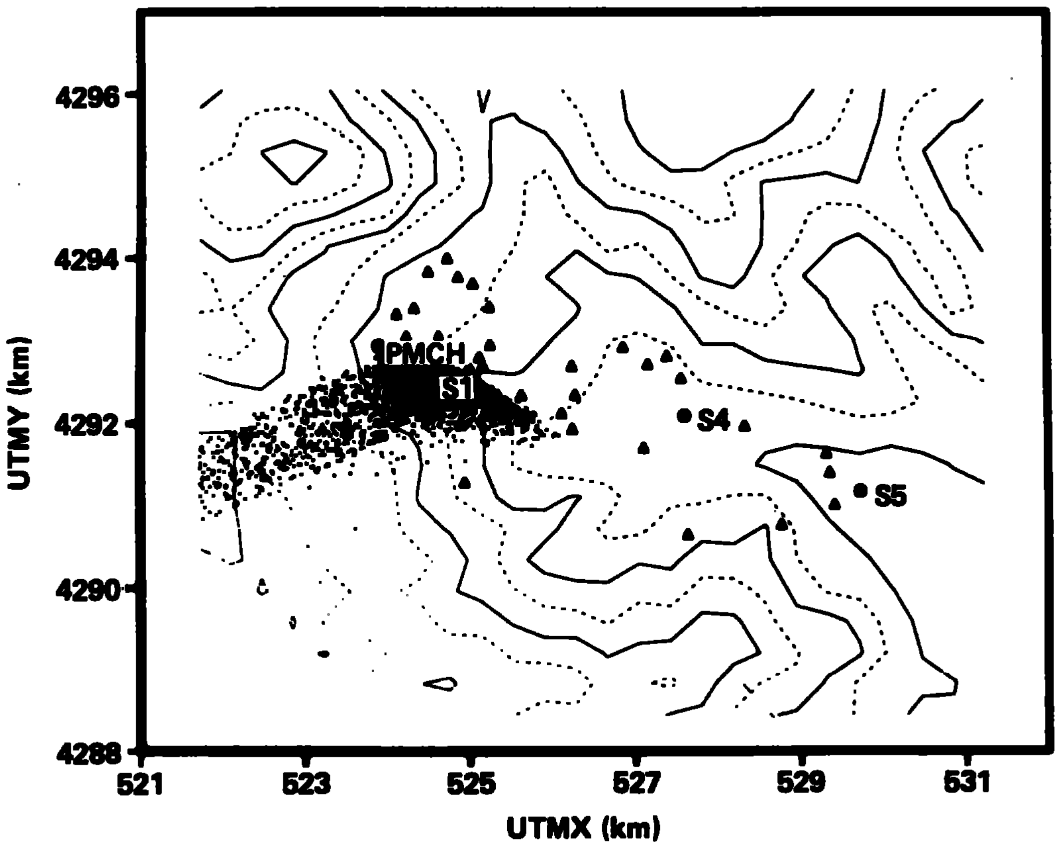

Figure 18. Computed trajectory of particles for Night 2 projected on the surface at 0000 PST. The particle release started at 2300 PST and lasted for one hour.

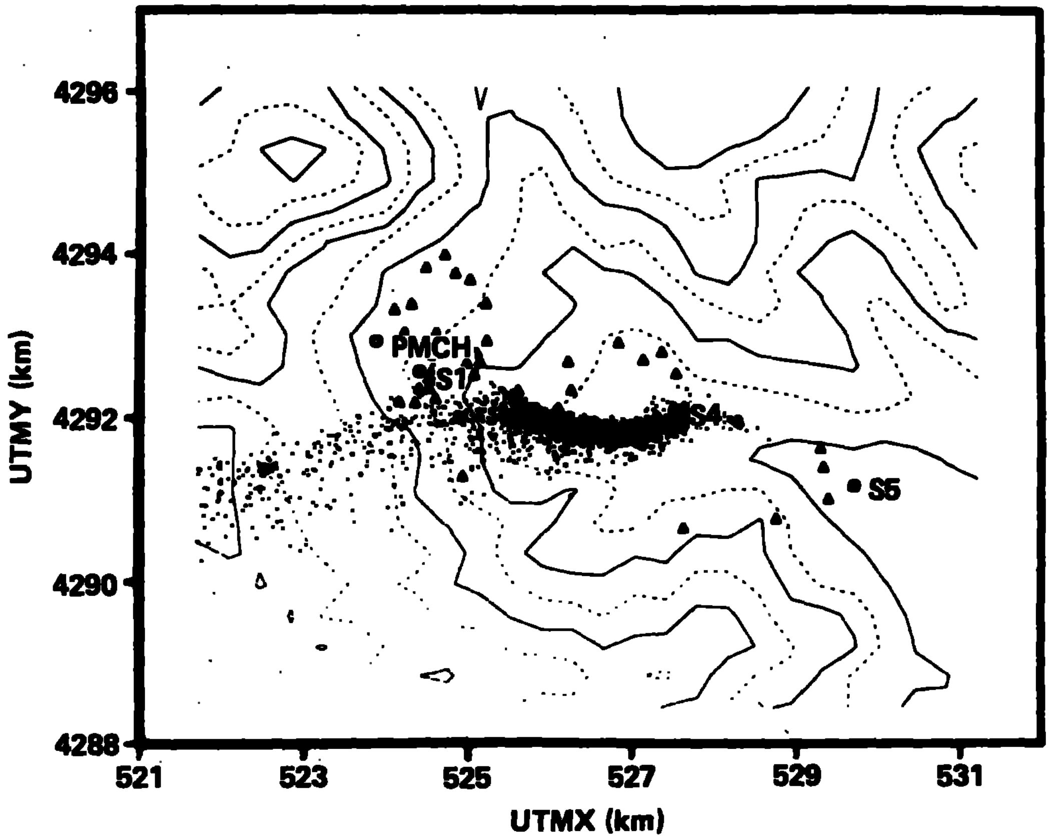

Figure 19. Same as in Figure 18 but at 0100 PST.

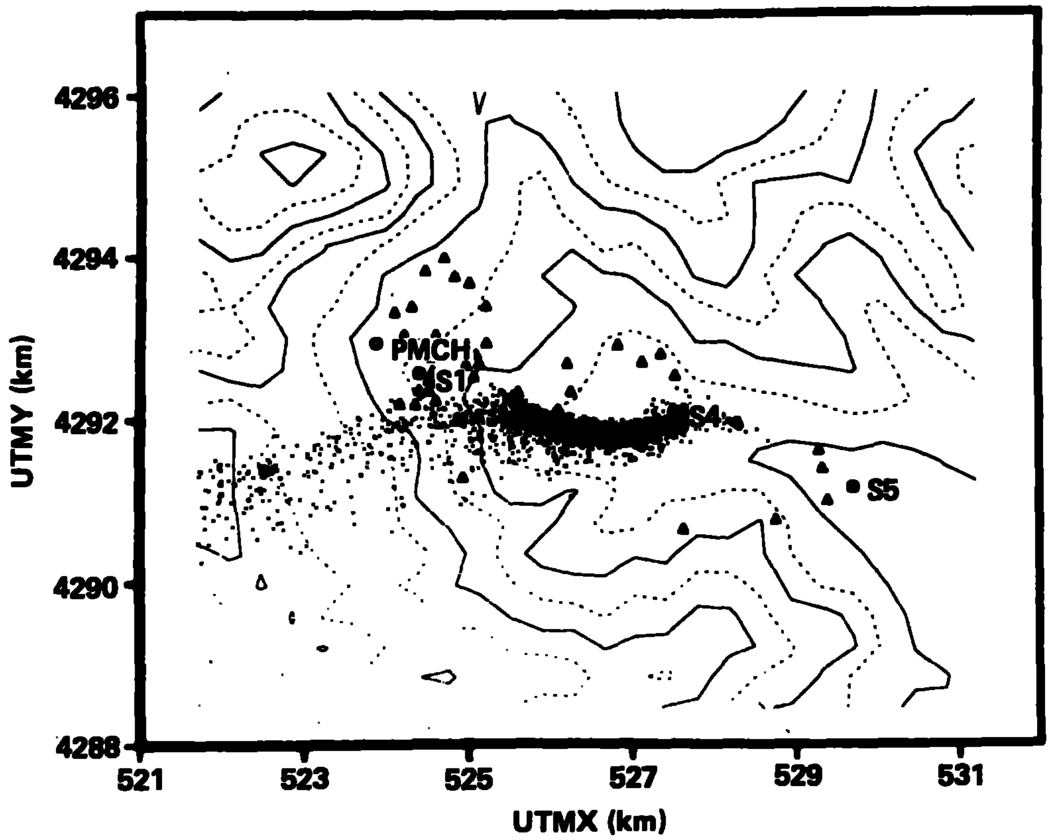

Figure 20. Same as in Figure 18 but at 0200 PST.

LIST OF ABBREVIATIONS

ARL - NOAA Air Resource Laboratory

ANL - Argonne National Laboratory

ATDL - NOAA Atmospheric Turbulence and Diffusion Laboratory

BNL - Brookhaven National Laboratory

CSU - Colorado State University

EML - Environmental Measurements Laboratory

JEA - Japan Environmental Agency

LLNL - Lawrence Livermore National Laboratory

LANL - Los Alamos National Laboratory

NWS - National Weather Service

ORNL - Oak Ridge National Laboratory

PNL - Pacific Northwest Laboratory

SNL - Sandia National Laboratory

SRL - Savannah River Laboratory

UW - University of Washington

WPL - NOAA Wave Propagation Laboratory

ASCOT PUBLICATIONS

P. H. Gudiksen and M. H. Dickerson (Ed.), "Executive Summary: Atmospheric Studies in Complex Terrain Technical Progress Report FY–1979 through FY–1983," ASCOT 84–2, Lawrence Livermore National Laboratory Report UCID–18878–83 Summary, 1983.

M. H. Dickerson and P. H. Gudiksen (Ed.), "Atmospheric Studies in Complex Terrain Technical Progress Report FY–1979 Through FY–1983," ASCOT 84–1, Lawrence Livermore National Laboratory Report UCID–19851, 1983.

C. J. Nappo., S. Barr, W. E. Clements, T. Yamada, W. Neff and W. Porch, "Report on the ASCOT Data Analysis Workshop," ASCOT 84–7, Lawrence Livermore National Laboratory Report CONF–8311213, 1984.

C. J. Nappo and L. C. Satterfield, "Portable Automated Mesonet (PAM) Data from the 1980 Experiment in Anderson Creek Valley," Atmospheric and Turbulence Diffusion Laboratory Report ASCOT 84–4, August 1984.

The following papers appear in the proceedings of the Third Conference on Mountain Meteorology sponsored by the American Meteorological Society and the USDA Forest Service. The conference was held on October 16–19, 1984 in Portland, Oregon.

R. Lange, "Relationship Between Model Complexity and Data Base Quality for Complex Terrain Tracer Experiments," Lawrence Livermore National Laboratory and L. O. Myrup, University of California, Davis, California.

C. J. Nappo and K. Shankar Rao, "A Numerical Investigation of Entrainment in Pure Katabatic Flows," Atmospheric Turbulence and Diffusion Division (ATDD)/National Oceanic and Atmospheric Administration (NOAA), Oak Ridge, Tennessee.

M. M. Orgill and R. I. Schreck, "Dissipation of Temperature Inversions and Drainage Conditions on a Mountain Slope," Battelle Pacific Northwest Labs. (Battelle NW), Richland, Washington.

R. B. Fritz, "Anomalous Zephyrs in Slope Winds," Wave Propagation Lab. (WPL)/NOAA, Boulder, Colorado.

C. D. Whiteman, "Atmospheric Mass Budget for a Deep, Narrow Valley in Colorado," Battelle Pacific Northwest Labs., Richland, Washington and Sumner Barr, Los Alamos National Lab., Los Alamos, NM.

David Whiteman, "Atmospheric Tracer Experiments in a Deep Narrow Valley," Battelle Pacific Northwest Labs., A. H. Huber, EPA, Research Triangle Park, NC, R. W. Fisher, EPA, Denver, Colorado and B. D. Zak, Sandia National Lab., Albuquerque, NM.

M. M. Orgill, R. N. Lee, R. I. Schreck, K. J. Allwine, and C. D. Whiteman, "Early Morning Ventilation of an SF6 Tracer From a Mountain Valley," Battelle Pacific Northwest Labs., Richland, Washington.

J. C. Doran and T. W. Horst, "Turbulence Structure of Nocturnal Slope Winds," Battelle Pacific Northwest Labs., Richland, Washington.

K. T. Foster and M. H. Dickerson, "A Comparison Between Tracer Measurements and Model Calculations for Nighttime Drainage Flows in Complex Terrain," Lawrence Livermore National Laboratory, Livermore, California.

W. M. Porch, R. Lange and D. E. Bennett, "Statistical Relationships Between Meteorological Data Stations and Implications to Diagnostic Models in Complex Terrain," Lawrence Livermore National Laboratory, Livermore, California.